**The Greenhouse Effect**

Objectives: The phrase greenhouse effect is central to discussions of global climate change. Upon completion of this activity, you should be able to clearly state the similarities and differences between the causes of warming inside a greenhouse and warming of the earth’s atmosphere due to greenhouse gases.

Causal principles:

1. **Temperature** is a measure of the movement of molecules. Higher temperature means molecules are moving faster.

Background information. Solar radiation comes in a wide range of wavelengths from ultraviolet (0.01 to 0.2 micrometers) to visible (0.2 to 4 micrometers) to infrared (4-100 micrometers). A human hair is about 40-50 micrometers thick.

Matter interacts differently with different wavelengths. For example, it is the short wavelength infrared that causes sunburn. Humans cannot see infrared radiation (IR) but some animals such as rattlesnakes can sense IR radiation. Warm objects emit infrared radiation and this allows rattlesnakes to detect them even in pitch dark. Of course, humans see objects that reflect solar radiation in the visible wavelengths. Each of these three cases indicates that solar radiation can interact with some molecules. The interaction is determined both by the wavelength of the radiation and the nature of the molecules. When solar radiation interacts with molecule, it causes them to move faster which results in an increase in temperature.

*How a greenhouse works*

A greenhouse is designed to allow most of the solar radiation to reach plants, which need solar radiation for photosynthesis, and to keep the plants warm. Some of the solar radiation is reflected from the glass. Also, glass will block very short wave ultraviolet radiation, which is the wavelength that causes sunburn. So, you can work in a greenhouse all day long without getting sunburned. Solar radiation that passes through the glass warms the soil, plants and everything else in the greenhouse. You have felt that same kind of warming on a cold sunny day when you are warmed by the bright sun. The soil, plants, etc. that are heated by the solar radiation, radiate heat into the air in the greenhouse just like heat radiates from black pavement on a sunny day. This is called sensible heat. The greenhouse glass prevents the hot air from mixing with the surrounding cooler air. The heated air is trapped within the greenhouse and may cause the temperature in the green house to rise too high. Therefore, most greenhouses have temperature sensitive vents that open when the greenhouse becomes too hot. The vents allow hot air to escape from the greenhouse and be replaced by colder air.

The glass that surrounds the greenhouse reflects long wavelength, infrared radiation. Therefore, this component of the solar radiation does not enter the greenhouse. However, the solar radiation that does penetrate the glass interacts with surfaces inside the greenhouse and these surfaces, when heated by solar radiation, emit infrared radiation that can heat the air inside the greenhouse. This infrared radiation is trapped within the greenhouse because the glass reflects it. Of course, this infrared radiation can escape through the vents in the greenhouse, when they are open.

How the greenhouse effect works

A thin layer of gases that we commonly refer to as air or atmosphere surrounds the earth. Nitrogen (78% by volume) and oxygen (21%) make up a total of 99% of the atmosphere. These two dominate components play no role in the greenhouse effect because they are transparent to incoming solar radiation and outgoing infrared radiation that is emitted from the earth’s surface. There are also several minor constituents of the atmosphere, such as water vapor and carbon dioxide, which are largely transparent

to the incoming solar radiation, but strongly absorb the infrared radiation emitted from the ground.

Water vapor is the most abundant greenhouse gas. It is also quite variable in the atmosphere. We can notice the difference in greenhouse effect of water vapor in the atmosphere by comparing daytime and nighttime temperatures in deserts and humid regions. In deserts, nighttime temperatures drop much more than they do in humid regions because the deserts have less “heat trapping “ water vapor in the air. The next most abundant gas in the atmosphere is carbon dioxide (CO2). Like water vapor and some other greenhouse gases, carbon dioxide absorbs infrared radiation and re-emits that radiation in all directions. Some of that radiation goes back toward the earth’s surface. The radiation absorbed by these gases is re-emitted in all directions, some back toward the surface leading to a net warming of the surface.

There are some negative feedbacks in the greenhouse effect that help stabilize temperature. For example, an increase in CO2 concentration in the atmosphere results in a warmer climate but the warmer climate and increase CO2 may stimulate plant growth that extracts CO2  from the atmosphere, which results in cooling of the atmosphere.

Figure 1 is an energy balance diagram from NASA (<http://asd-www.larc.nasa.gov/erbe/components2.gif>) that shows the total energy flux from the sun to the earth and the role of greenhouse gases. The left side of the diagram shows the incoming solar radiation. The largest portion of this radiation is what we refer to as visible light with a wavelength between 0.2 and 4 micrometers. A human hair is about 40-50 micrometers thick.

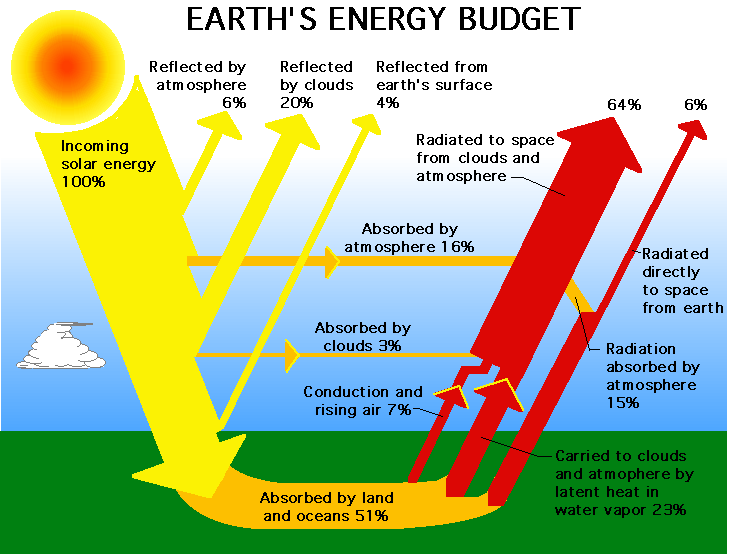


Figure 1. Solar energy balance diagram

Approximately 30 % of the incoming radiation is reflected back into space. This reflected radiation does not heat the atmosphere. About 19% of the incoming radiation is absorbed by clouds, which are made of water vapor and other greenhouse gases. This portion of the incoming radiation does contribute to heating the atmosphere. Fifty-one percent of the incoming solar radiation is absorbed by the land and ocean surfaces. This absorbed energy is transferred back to the atmosphere in several ways and eventually the outgoing radiation must balance the incoming radiation. The heat from the ground that is transferred by what is referred to as conduction and rising air is called sensible heat. This is the same as the heat you feel as you pass your hand over a hot object. Greenhouse gases contribute to this balance by absorbing some of the energy that is radiated from the ground in long wavelengths (infrared radiation, 4 -100 micrometers). This absorbed energy is re-emitted from the greenhouse gases and contributes to the warming of the atmosphere.

One way to understand the role of energy balance and the effect of greenhouse gases is to draw an analogy with water flowing into and out of a reservoir. The height of the water in the reservoir is determined by the rates of water inflow and outflow (Figure 2). In figure 2B the size of the outflow tube is smaller and this results in slower outflow of water. As a result, the height of the water in the reservoir increases. The height of water in the reservoirs is similar to the temperature of the earth’s atmosphere and the slower outflow in figure B is similar to the effect of greenhouse gases on the radiation balance.

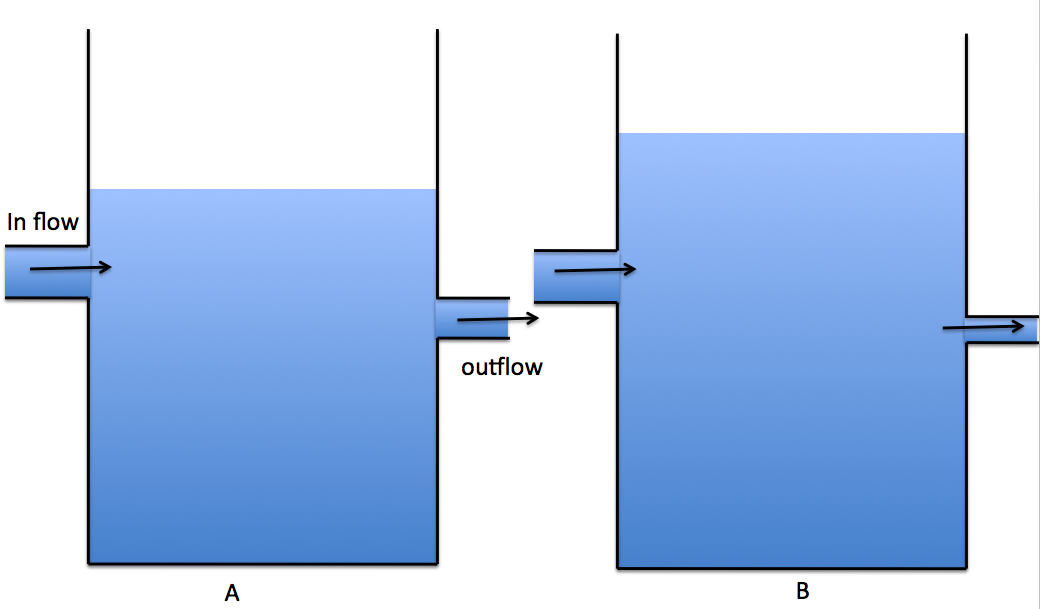


Figure 2. A reservoir analog for the effect of greenhouse gases on the temperature of the atmosphere.

**Part A. Alignment of Feature and Factors affecting the temperature of a greenhouse and the atmosphere**

A greenhouse is often used as an analog for the greenhouse effect of the earth’s atmosphere. That is, many elements and relationships correspond. Before aligning the a greenhouse with the greenhouse effect in the atmosphere (Table 3), place each element of a greenhouse (Table 1) and each element of the greenhouse effect (Table 2) in correspondence with statements about how these elements effect temperature in the greenhouse or atmosphere.

Table1 lists a variety of elements of the description above of how a greenhouse works. For each element listed, describe that element’s role in causing or affecting the temperature inside a greenhouse.

Table 1

|  |  |
| --- | --- |
| **Elements** | **Causes and effects on temperature** |
| glass | *Allows solar radiation into greenhouse. Prevents hot air from escaping* |
| vents | *Allows hot air to escape to prevent the temperature from getting too high* |
| Soil, plants, and other surfaces in greenhouse | *Absorb visible light and emit IR*  *Also directly heat air* |
| Infrared radiation | *Generated from surfaces inside the greenhouse.* |
| Sensible heat | *Increases the temperature of molecules in the air.* |
| Reflection of IR radiation off the glass | *Prevents incoming radiation from heating the inside of the greenhouse.* |

Table 2 lists elements of the description above of how the greenhouse effect works. For each element listed, describe that element’s role in causing or affecting the temperature inside a greenhouse.

Table 2

|  |  |
| --- | --- |
| **Elements** | **Causes and effects on temperature** |
| Energy balance | *The ratio of influx to outflux determines the temperature of the atmosphere.* |
| Greenhouse gases | *Absorb IR radiation from the earth’s surface. Slows the energy outflow, thus warming the atmosphere* |
| clouds | *Reflect incoming solar radiation* |
| Negative feedback | *Stabilizes temperature* |
| Infrared radiation | *Generated from surfaces inside the greenhouse.* |
| Sensible heat | *Increases the temperature of molecules in the air.* |
| Earth’s surface | *Absorbs solar radiation and emits IR radiation that may interact with greenhouse gases* |

In table 3, you will align elements of a greenhouse from table 1 with elements from the greenhouse effect in the atmosphere from table 2. There maybe one or more elements of each that do not match so some boxes in the two element columns may be blank. Also, an element may be correctly placed in more than one box.

Table 3

|  |  |  |
| --- | --- | --- |
| **Greenhouse elements** | **Greenhouse effect elements** | **Causes and effects on temperature** |
| glass |  | *Allows solar radiation into greenhouse. Prevents hot air from escaping.* |
| vents | *Negative feedback* | *Stabilizes temperature* |
| soil, plants, and other surfaces in greenhouse | *Earth’s surface* | *Absorbs solar radiation and emits IR radiation* |
| infrared radiation | *Infrared radiation* | *Generated from surfaces inside the greenhouse.* |
| sensible heat | *Sensible heat* | *Increases the temperature of molecules in the air.* |
| reflection of IR radiation off the glass |  |  |
|  | Energy balance |  |
| *glass* | Clouds | *Reflect incoming solar radiation* |

**Part B. Important Alignable Differences between a greenhouse and the greenhouse effect**

Making analogies isn’t just about finding what’s similar between two domains, but also discovering and understanding important differences. Answer the following question that emphasizes an important difference.

1. Explain why the thickness of greenhouse glass does not play the same role as the amount of greenhouse gases in the atmosphere.

**Assessment**

Global climate responds to changes in the natural, decade long variations in the dimming and brightening of the sun. If the concentration of greenhouse gases in the atmosphere continues to increase, will variations in solar radiation have the same, less, or more impact on climate? Please explain your reasoning.